

Information modeling system for blast furnace control

N A Spirin, L Y Gileva and V V Lavrov

Department of Thermophysics and IT in Metallurgy, Ural Federal University, 19 Mira Street, Ekaterinburg, 620002, Russia

E-mail: spirin@urfu.ru

Abstract. Modern Iron & Steel Works as a rule are equipped with powerful distributed control systems (DCS) and databases. Implementation of DSC system solves the problem of storage, control, protection, entry, editing and retrieving of information as well as generation of required reporting data. The most advanced and promising approach is to use decision support information technologies based on a complex of mathematical models. The model decision support system for control of blast furnace smelting is designed and operated. The basis of the model system is a complex of mathematical models created using the principle of natural mathematical modeling. This principle provides for construction of mathematical models of two levels. The first level model is a basic state model which makes it possible to assess the vector of system parameters using field data and blast furnace operation results. It is also used to calculate the adjustment (adaptation) coefficients of the predictive block of the system. The second-level model is a predictive model designed to assess the design parameters of the blast furnace process when there are changes in melting conditions relative to its current state. Tasks for which software is developed are described. Characteristics of the main subsystems of the blast furnace process as an object of modeling and control – thermal state of the furnace, blast, gas dynamic and slag conditions of blast furnace smelting – are presented.

1. Introduction

Control of blast furnace operation is often classified as poorly structured problem. Because of this the base mathematical models have to be used at automated workstations of engineering and technological staff of blast furnace. The software for computer decision-making support system is a set of information-connected interactive (dialog) program modules integrated into a common environment. Integration of mathematical models is based on the application of both common initial data and the results of calculations performed by individual modules. Software modules implement mathematical models of heat-exchange, slag, blast and gas-dynamics regimes of blast furnace. This forms the basis of functionality of the decision making support system while the modular structure ensures its extensibility.

Solution of the problems of analysis and forecast of blast furnace operating parameters using available actual information on furnace performance requires decomposition of the problem into three main interrelated subsystems: the thermal condition of the furnace, blast and gas dynamics regimes of blast furnace, slag regime. The basic principle, which underlies the choice of specific mathematical equations to describe the individual subsystems, is to resolve the contradiction between the complexity of the modelled process and the need to resolve the technological problems in real time in course of the process and for a specified time interval using the actual available information.



2. Mathematical model

Modern advances in the theory and practice of the blast furnace process used as the basis of mathematical modelling [1–8]. Usage of the principle of mathematical modelling [2–5, 9–13] based on deviation of the actual operation from the base period of operation requires allocation of two levels of model: the basic state model and the predictive model. The basic state model allows estimation of the vector of system' parameters, This model is used to estimate adaptation coefficients of predictive model. The predictive model estimates the design parameters of blast furnace process when conditions of blast furnace operation deviate from the base state.

The initial data for the base state model is the data of the blast furnace operation in the period of time in which the dynamic measurement errors are negligible (base period). Conditions of the furnace operation in the base period should be stable and be close to the current state (current period), as the use of linear equations describing the nonlinear process is limited by the parameters of its nonlinearity. The current period is a period of furnace operation immediately preceding the time simulation. Data on furnace operation in the current period is required for the initial (baseline) data for projecting of blast furnace performance indicators in the case of change in raw materials or regime parameters. Additional data for predictive model are the vector of indicators of the state of the system, which is estimated in the base period model, and a set of data on changes in parameters of blast furnace operation relative to the current period (projected period).

A block diagram of computer decision support system is shown in Figure 1. The following subsystems are included in block diagram Figure 1.

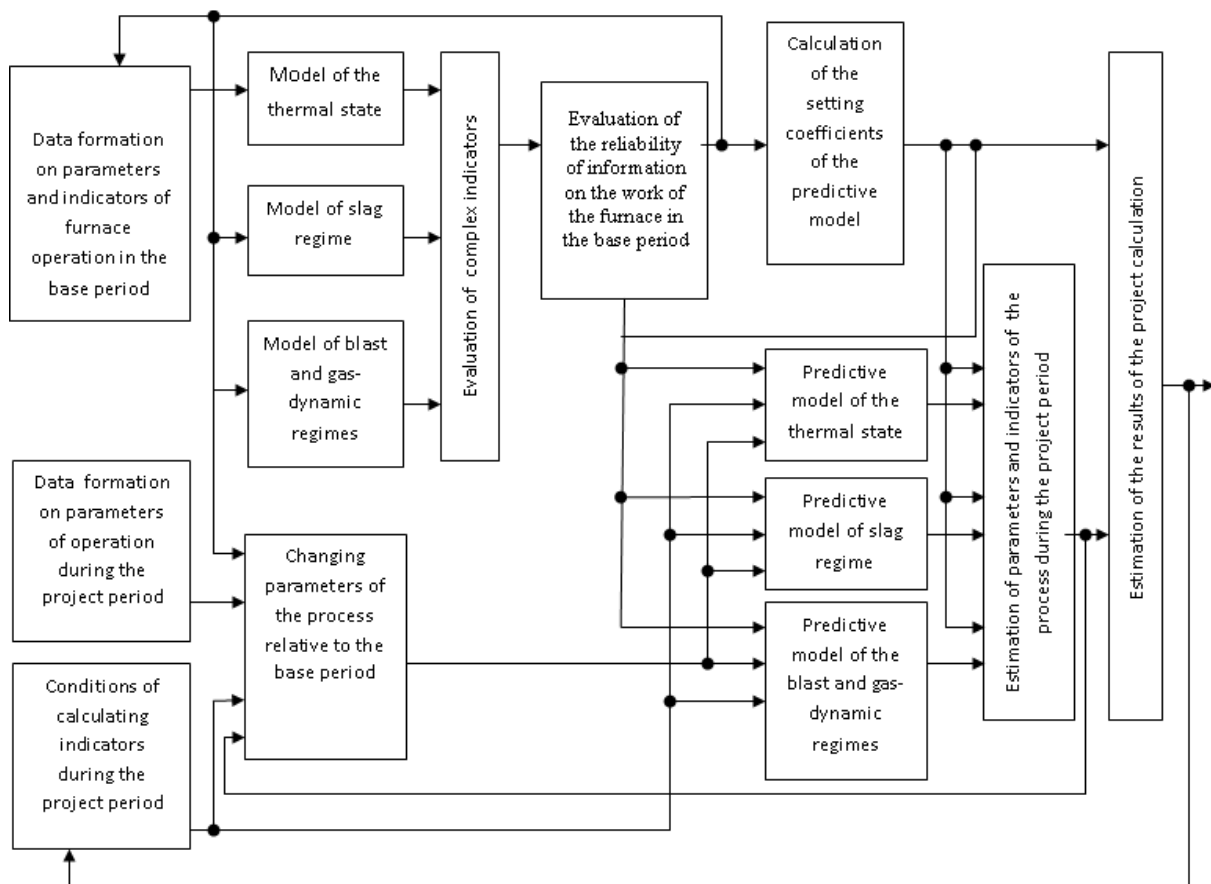


Figure 1. Block diagram of a computer decision support system.

Subsystem of blast furnace thermal state [1–5, 9]. Figure 2 illustrates the ideology of using this subsystem to estimate the required changes in coke rate in response to changes in burden quality. This subsystem has two major goals: assessment of the effect of regime parameters on the specific consumption of coke (ore load); forecast of chemical composition of smelting products at changes in parameters of burden and combined blast.

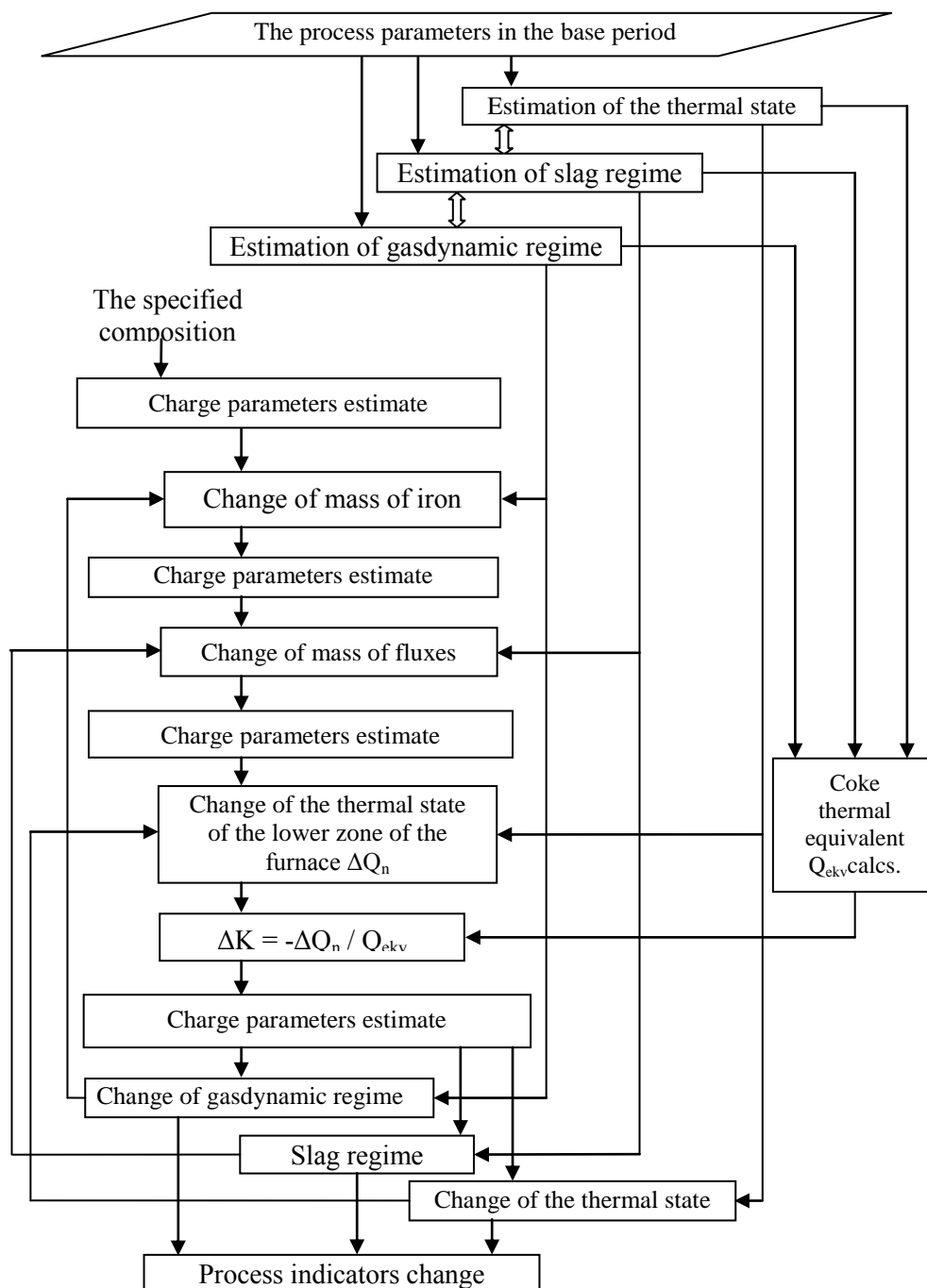


Figure 2. Algorithm to estimate the required changes in coke rate in response to changes in burden chemistry.

Regularities of heat transfer in modern blast furnaces form the basis of the thermal state model. These regularities confirm the possibility of independent evaluation of the upper and bottom heat exchange zones of blast furnace. The upper thermal zone determines the intensity of indirect reduction of iron. The lower thermal zone determines demand of enthalpy for the direct reduction of wustite and physical and chemical heating of slag and hot metal. The influence of the thermal state of the upper zone on the thermal state of the lower zone is developed through extend of direct and indirect reduction processes. Heat and mass balance relations of the model are supplemented by heat transfer equations to estimate the effect of gas flow performance and slag regime on heat conditions of the blast furnace.

Subsystem of blast and gas dynamics regimes [1–5, 10]. A block diagram of a gas dynamics modelling is shown in Figure 3. The gas dynamics modelling allows solution of the following set of problems:

- assess the impact of combined blast and burden parameters on raceway operation;
- estimate gas-dynamics parameters of materials' column;
- estimate the pressure drop along the furnace height;
- determine the reserves to increase intensity of blast furnace operation by parameters of blast.

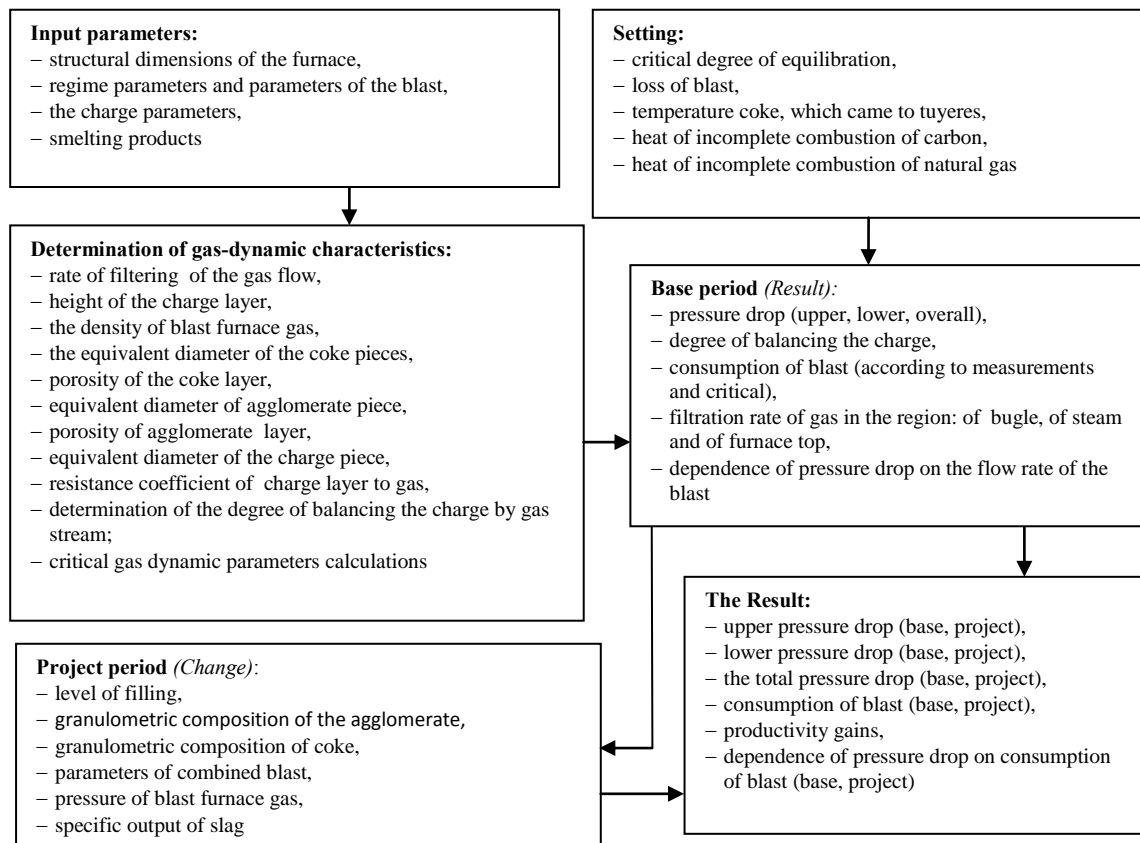


Figure 3. Block diagram of gas dynamics modelling.

Subsystem of slag regime [1–5, 11]. This subsystem evaluates the slag regime of blast furnace. Several problems have to be solved in the course of slag formation modeling at all stages of the process: materials fusion; filtration of primary slag through the coke bed; obtaining the final slag; obtaining the hot metal with desired chemical composition including minimum sulfur content. Block diagram of slag regime subsystem is presented in Figure 4.

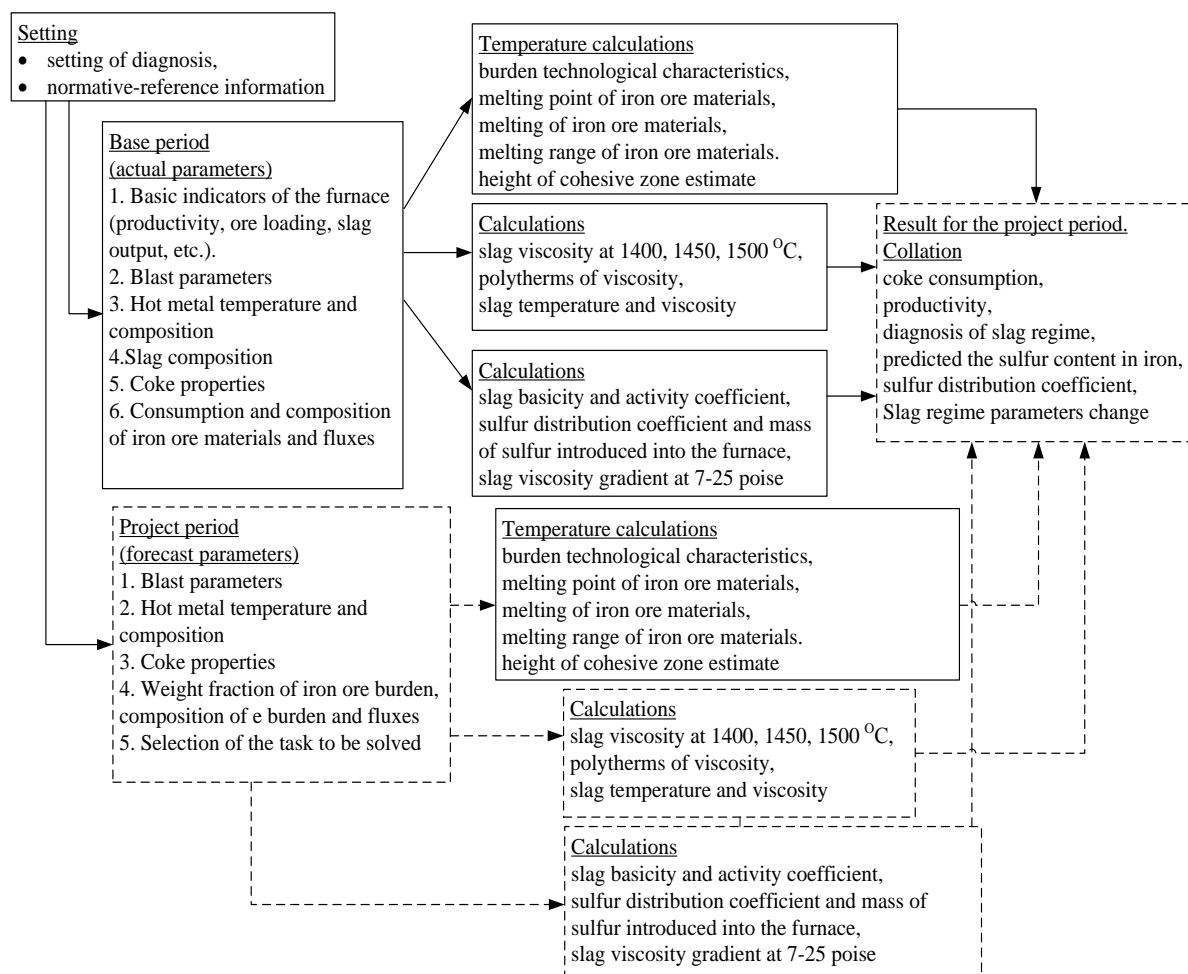


Figure 4. Block diagram of the slag regime modelling.

Four component slag system – $\text{CaO-SiO}_2\text{-MgO-Al}_2\text{O}_3$ in area of the real values of blast furnace slag plus known relationship between slag viscosity and its temperature are used for analytical estimation of slag viscosity for base and predictive periods. If significant quantities of other oxides are present in slag appropriate corrections are introduced taking into account the influence of these oxides on slag viscosity.

The dependence of blast furnace slag viscosity on temperature in the temperature range of 1350–1550 °C for the base period, as well as for the case of change in blast furnace operating conditions is estimated using the relationship between temperature and viscosity of homogeneous slag. The temperature of formation of the first portion of liquid phase (corresponds to the start of shrinkage – the temperature of start of fusion) and melting temperature (the temperature of the movable melt formation) are estimated by empirical equations for specific iron bearing material. Sulfur balance equation is used to predict sulfur content in hot metal. Detailed description of the subsystem of slag regime could be found in literature [3–5].

3. Results of modelling

The initial information on operating parameters and indicators of blast furnace is automatically extracted from the database to form the dataset of the furnace operation in the base period. Manual entry of the data and duration of the base period is envisaged. The period with duration of 24 hours (or one shift) closest to the current period of operation is set by default. The set of parameters which

characterize heat, wind (blast), gas dynamics and slag regimes of the blast furnace is estimated during base period modelling (Table 1).

Table 1. Major indicators of blast furnace operation.

Indicators	Shift 1	Shift 2	Shift 3
Production, thm/period	1102	1215	1001
Theoretical productivity, thm/period	1116	1170	1179
Performance (actual/estimated), thm/day:	3340/3382	3681/3546	3033/3573
Coke consumption (Estimated production/minimum), kg /thm	430.5/390.7	428.3/373.0	431.4/381.3
Volumetric intensity index, tons of coke/(m3 per day)	1.05	1.10	1.11
Ore load (per wet coke) t/t	3.77	3.77	3.77
Degree of direct reduction, fraction.	0.30	0.34	0.33
Content of Fe in the iron part of burden, %	58.92	59.23	58.86
Hot metal temperature, 0C	1412	1405	1406
Slag volume (Actual/estimate), kg/ thm	310/298	312/289	334/296
Slag basicity CaO/SiO ₂ (actual/estimate), fraction	1.04/1.13	1.09/1.13	1.09/1.13
Slag viscosity at t=1500 0C (C-S-A)/ (C-S-A-M):	5.00/3.34	5.02/3.34	4.95/3.27
Sulfur distribution coefficient (Ls)	45	67	55
Temperature of melting/ temperature of slag good fluidity, 0C	1342/1494	1340/1494	1341/1491
Wind (blast) rate (actual/marginal), m3/min	3032/3267	3128/3401	3090/3242
Blast pressure (actual/marginal), atm.	2.71/2.91	2.76/3.00	2.76/2.90
Pressure drop along the burden height (actual/marginal), atm.	1.32/1.53	1.29/1.53	1.39/1.53
Equilibration degree of charge by gas flow (actual/marginal), %	47/55	47/55	50/55
Natural gas rate, % to wind rate	9	10	8
Raceway length, mm	1208	1222	1394
Oxidizing zone length, mm	1546	1564	1784
Oxidizing zone relative area, %	46	47	59
RAFT, 0C	1919	1933	2055
Top gas rate, m3/min	3912	4139	4540
Utilization degree of CO, fraction.	0.43	0.45	0.43
Thermal efficiency, %	66	67	62
Thermal state of the bottom zone indicator, MJ/thm	2870	2818	3342
Thermal equivalent of coke' carbon, kJ/kg Coke	9657	9638	11185

4. Conclusions

Experimental and industrial operation of the pilot expert system to control blast furnace operation and support management' decision making process demonstrates the correctness of the computational algorithm, the possibility of model adaptation and tuning to the specific conditions of individual blast furnace and the whole blast furnace shop

Developed software, with appropriate adaptation can be recommended for the following applications:

- control of blast furnace operation in real time;
- create automated workplaces for engineering staff of blast furnace shop;
- solution of the complex strategic problems for production planning, supply of iron ore and fuel, optimal energy management, etc.

5. Acknowledgements

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6. References

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